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Automotive and Construction Equipment for Arctic Use Heating and Cold Starting

Deborah Diemand

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USA Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755-1290

Automotive and Construction Equipment for Arctic Use Heating and Cold Starting

Deborah Diemand

Equipment heating requirements in the extreme cold

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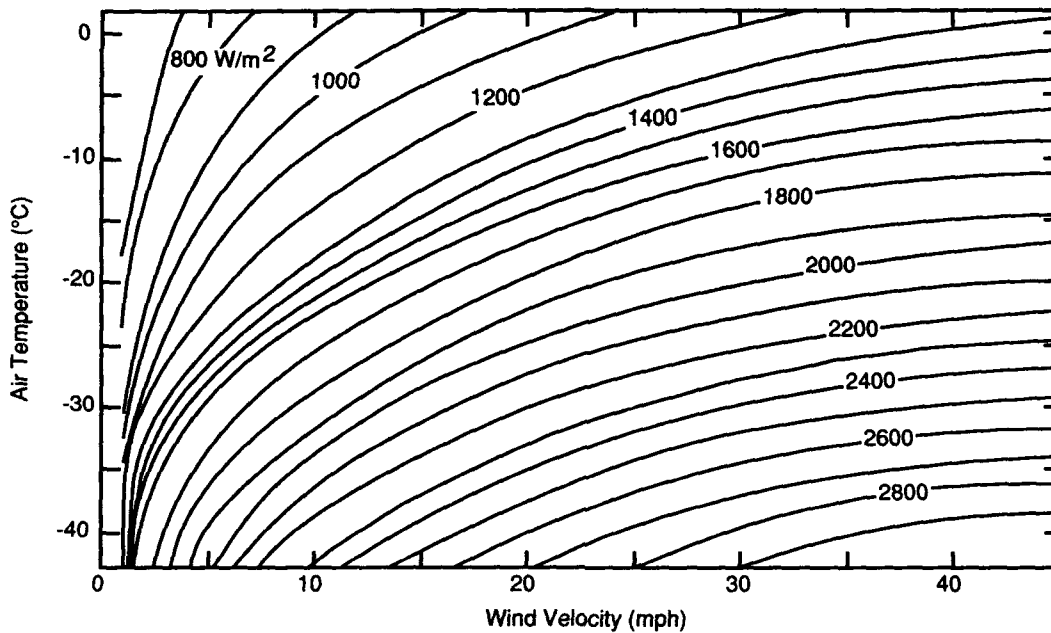


The author, a
physical scientist, is a
member of CRREL's
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Low-temperature problems with automotive equipment begin to appear at about 0°C. Lubricants thicken, batteries lose power, and water in the fuel, oil or other fluids begins to cause problems. Diesel engines that have not been winterized become difficult to start, and they may not start at all at temperatures below -10°C. Gasoline engines start more reliably in the cold, but they suffer the same problems with regard to lubricants and batteries. The solution to these problems is heat. The amount of heat required and the means of applying it cannot be determined simply, as this will depend on the ambient temperature, wind speed, engine size and type, and degree of winterization of the engine. There are commercially available heaters for the following vehicle components:

- engine block;
- oil pan;
- batteries;
- fuel tanks, lines and filters;
- transmissions, differentials and transfer cases;
- air intake;
- combustion chamber;
- engine compartment air; and
- personnel and cargo compartments.

Wind speed has a considerable effect on the amount of heat required to raise the temperature of a cold-soaked engine to a level at which it will start, and its effect on the cooling rate of a piece of equipment both during operation and after shutdown is significant.



1. Heat loss at various temperatures in the presence of wind. (After Northrop Services, Inc. 1980.)

Figure 1 shows the heat loss experienced by a warm object in cold air at various wind speeds. While the equipment can never be cooled below the ambient temperature regardless of wind speed, the wind greatly increases the rate at which cooling to this temperature takes place. Thus, the size, type and number of heaters required for equipment depend to a great extent on where it will be parked when not in use. Machinery parked in a heated garage will need little more than a heavy-duty cab heater for operator comfort during operation. If the equipment is parked in an unheated garage, small block and pan heaters in conjunction with suitable low-temperature lubricants may be sufficient. If the machinery is exposed to high winds and low ambient temperatures, on the other hand, heat must be supplied to the block, pan, battery and other components, depending on the type of equipment, and the engine compartment should be well insulated.

The ubiquitous Herman Nelson heater is frequently used when a cold-soaked machine is to be started. Heaters of this type use liquid fuel and deliver forced hot air. They range in size from units about the size of a vacuum cleaner to trailer-mounted models (such as that shown in Fig. 2), with power ratings from about 40,000 Btu to more than 1,000,000 Btu (about 12–300 kW). When these heaters are used, the entire piece of equipment is usually warmed to ensure that all systems, including drive train, hydraulics, controls, etc., are



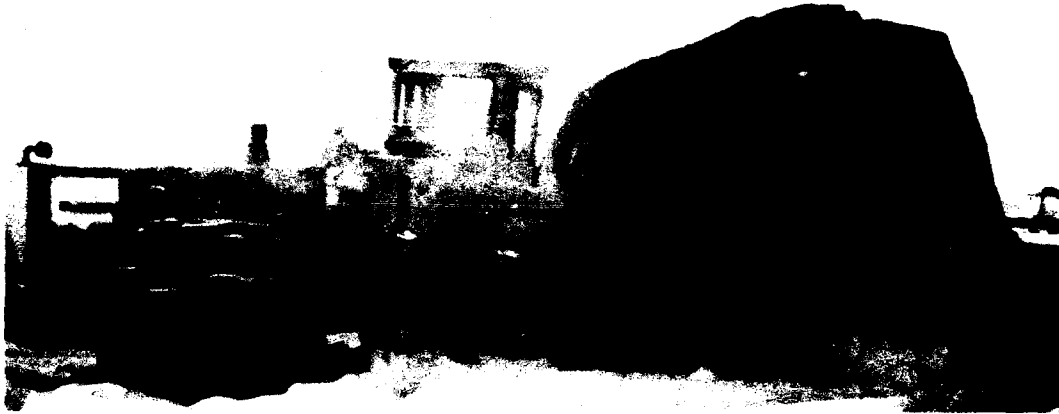
2. Large Herman Nelson heater fitted with an elephant trunk hose to direct the heat to desired location.

sufficiently warm to operate without damage or undue wear due to thickened lubricants and fluids. This is normally accomplished by covering the equipment with a tarpaulin, plastic shelter or other portable shelter. Figure 3 shows a cold-soaked loader being heated with a 450,000-Btu (about 130 kW) space heater. The loader is covered with a parachute to retain the heat, a common practice in Alaska. This process would normally take 2–4 hours.

Engine preheating is either continuous during shutdown (standby heating) or on demand for a short time prior to starting a cold-soaked engine (quick-start). The main difference between standby and quick-start heaters is the heat output.

Quick-start heaters must have a much greater output than standby heaters, usually 200,000 Btu/hr or greater (about 60 kW), because they must heat a cold-soaked engine to normal operating temperature within a relatively short time. The shortest possible time is preferred, but because of the size of heater required and the damaging effect of raising the temperature of engine parts too

Engine heaters



3. Bucket loader being heated prior to operation by enclosing it in a parachute and blowing hot air into this enclosed space through an elephant trunk conduit from the space heater on the left. The air temperature is about -37°C (-35°F).

rapidly, the time for heating is limited to 15 minutes to 1 hour at -55°C , depending on engine mass. In general the shorter the time allotted for preheating, the greater the size of the heater required and the greater the complexity of the preheating system. Quick-start systems may be more energy efficient than standby heaters and are preferable to prolonged idling, which shortens engine life. Moreover they are virtually essential when cold-soaking of a vehicle is unavoidable.

While preheating systems that provide heat to both engine and cab are commonly available, some operators direct heat only to the engine. This serves two purposes. First, more heat is available to the engine to assure an easy start. Once started, the normal cab heater can begin to heat the cab as the engine and coolant warm to operating levels. Second, since nobody wants to start off in a cold cab, operators will be more likely to allow the equipment to warm up properly while they drink a cup of coffee in the lunch room, rather than starting off immediately, which increases engine wear and unnecessarily strains cold engine parts.

Standby heaters generally have an output in the range of 10,000–30,000 Btu/hr (about 3–9 kW). They take many forms, including electric heating pads (and even light bulbs), coolant heaters, a continuously idling engine, and a hibachi with hot coals placed beneath the engine. They are usually turned on either manually or automatically when the equipment is shut down and either run continuously or intermittently through thermostatic controls to maintain a low level of heat in the engine during the shutdown

period. Because of their low heat output, they are generally not suitable for preheating a cold-soaked vehicle, although some can be turned on several hours before the equipment is needed using an automatic timer, which will allow the equipment to warm sufficiently to start.

Because coolant heaters employ a liquid heat-exchange medium, they are applicable only to liquid-cooled engines. In-line electric coolant heaters are commonly used on the North Slope of Alaska. Circulation of the heated engine coolant is either by thermosiphon action or by a small electric pump on the heater. When warm coolant is circulated by natural convection, the heat may become concentrated in a small area because of the cold-thickened coolant. This could potentially lead to local overheating, resulting in component warping and thermal cracking. When coolant is pumped, heat is not only provided to the cylinders, thereby warming the combustion chamber and the oil along cylinder walls, but it can also be used to heat other components, such as the fuel line, fuel tank, batteries and so forth, by using heat exchangers. The distribution of heat, since it is directly related to the flow of coolant, can be controlled to a greater extent. The only drawback is that a power source is required for the pump.

There are three classes of engine heaters in common use:

- Electric resistance heaters installed in or on the engine;
- Fuel-fired heaters that are permanently installed on the equipment; and
- Independent heating units that are connected to the equipment only long enough to achieve a successful start.

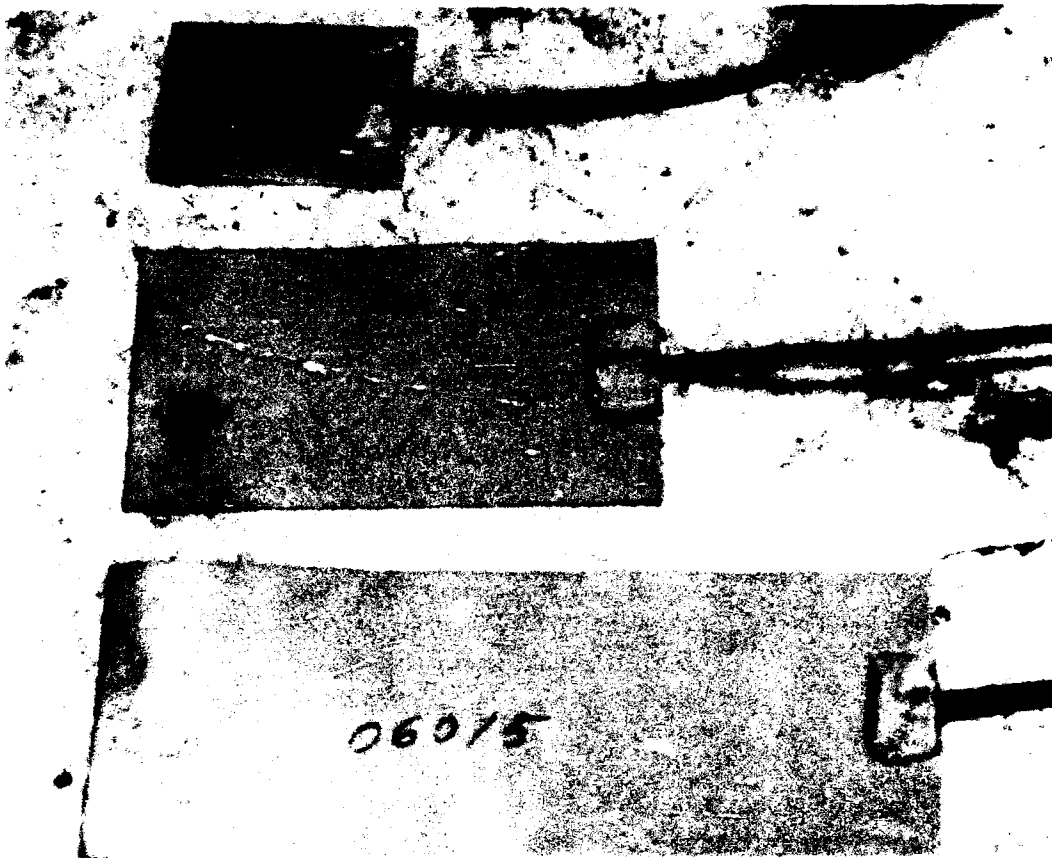
There are also a number of unconventional methods that have been used with varying degrees of success and risk. Some of these will also be mentioned briefly.

The chief advantages of using electric heaters are that they are inexpensive, compact and convenient. In a vehicle containing several heaters, e.g. battery pad, block and pan heaters, these are normally wired so that only one electrical outlet is required for all of them. This is effective and satisfactory for small vehicles in areas where outlets in parking areas are commonly provided. However, most such outlets are standard 20-amp circuits and cannot sustain a load greater than 2400 W. Therefore, larger machinery will require other types of heaters, as will equipment operating in areas where electric power is limited or unavailable.

Electric heaters

Externally mounted heating coils, tapes and pads are widely available and commonly used for heating specific areas and com-

Externally mounted
electric heaters

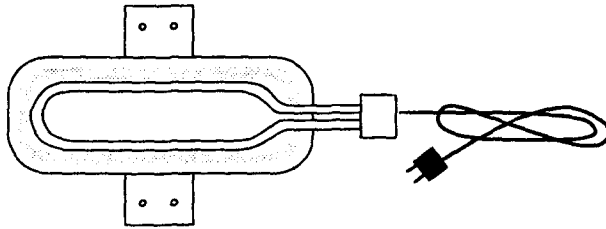


4. Silicone heating pads (150, 300 and 450W) ranging in size from about 3×5 in. to 6×14 in. These are attached to the oil pan or other flat surface using high-temperature silicone adhesive.

ponents, such as the engine block or battery. They rarely draw more than 500 W, but they take up little space and are easily installed. Battery pads and blankets are discussed in Diemand (1991a).

One of the most useful recent developments for extremely cold operations is the so-called silicone heater. This is a thin pad of silicone rubber with embedded heating elements. It can be glued to almost any surface using silicone high-temperature cement, takes up very little space, and is supplied in numerous sizes, the wattage being generally related to the physical dimensions of the pad. Three common sizes are shown in Figure 4, ranging from 150 to 450 W. These are widely used in the Arctic on oil pans and automatic transmissions and occasionally on hydraulic tanks and other troublesome components. These and other similar heaters are very valuable for preheating air-cooled engines.

Other types of externally mounted electric heaters for engines are available and are mounted with clamps or brackets. They are



5. Typical externally mounted clamp-on engine heater.

normally composed of a heating element with a reflector such as that shown in Figure 5 and are rated at 200–500 W. Small magnetic units similar to these are also available and can be applied to any surface that will accept a magnet. They produce about 200 W of heat and may be useful in some circumstances, although permanently installed units are preferable in most cases. In general these heaters are not suitable for preheating a cold-soaked engine because of their low energy output, but they are commonly used for stand-by heating.

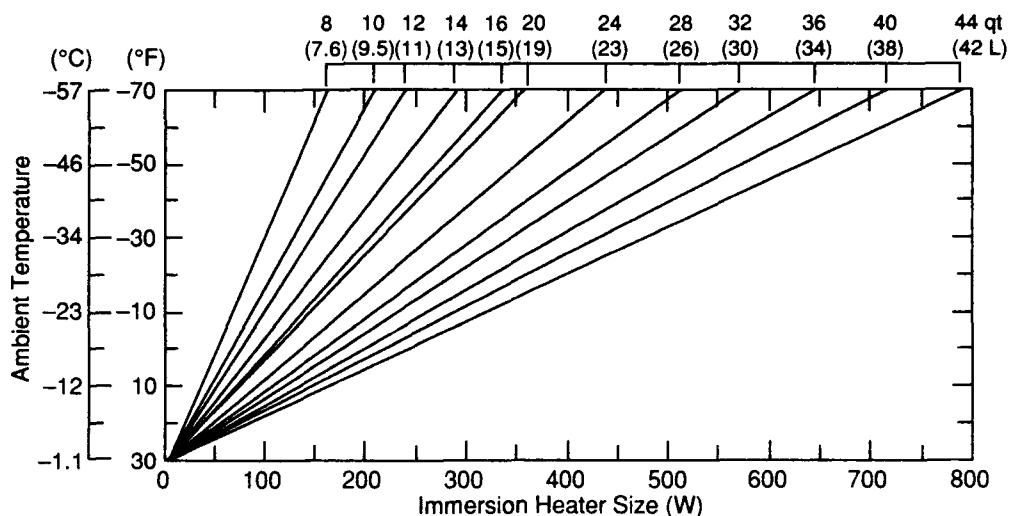
These heaters are installed so that the heating element is situated within the oil pan or coolant system. Since the heat loss is less than for the externally mounted types, the power requirement for the same result is less. However, installation is somewhat more complicated and may require draining the oil or coolant. Moreover, some engines may lack the necessary access ports. Nevertheless, one or more of these heaters are usually installed on equipment routinely used at very low temperatures.

Electric immersion heaters

The simplest of these is the dipstick heater, which fits most vehicles. The heating element is confined to the lower few inches of the shaft, and it usually draws less than 100 W. By itself it would be of little use in extremely cold conditions.

Heating elements that fit into the oil drain plug are more commonly used, and in conjunction with a block heater, they ensure that the engine oil is sufficiently fluid for successful engine starting. The need for this is discussed in Diemand (1991b). Immersion heaters of this type are available in wattages ranging from about 150 to 500 W and may also be used to warm transmission oil and coolant. Figure 6 shows recommended immersion heater wattages for different sizes of oil pans at low temperatures. In large engines with two oil pans, the required wattage obtained from the graph should be divided in half and a heater with this half-rating installed in each pan.

The most common locations for coolant immersion heaters are in the freeze plugs on the water jacket and in the lower radiator hose, although almost any access port, plate or plug located below the highest point in the cooling system appears to work. Since these

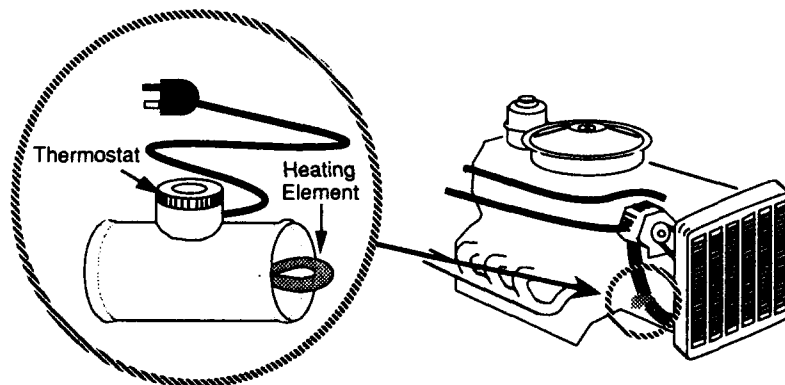


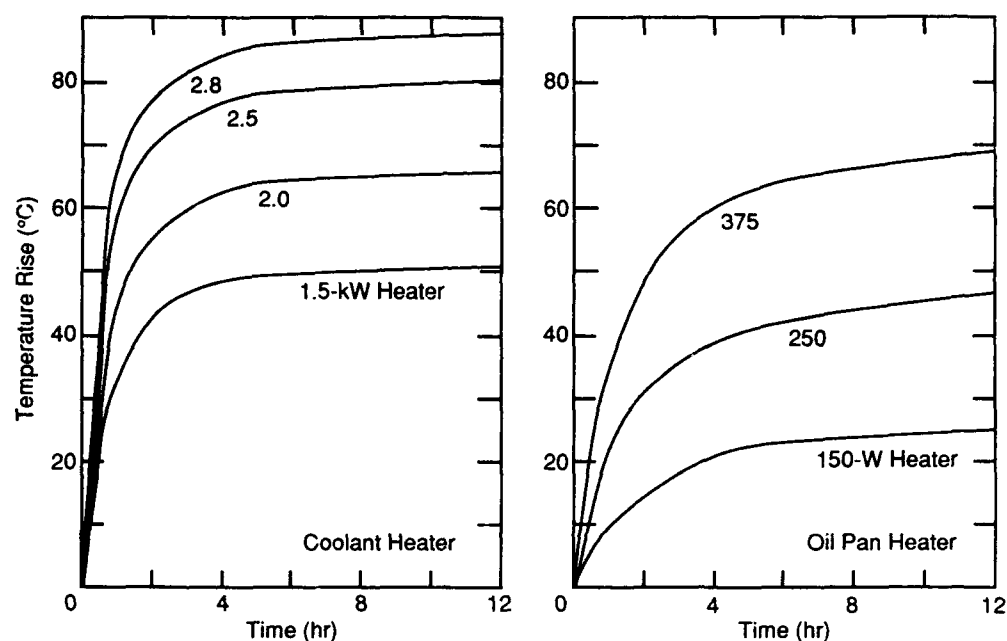
6. Immersion heater wattage required to raise the oil in the oil pan to -1.1°C ($+30^{\circ}\text{F}$). (After Detroit Diesel 1989.)

devices supply heat to the engine through convection, they are most effective when placed as low as possible in the cooling system. For the same reason, they cannot warm areas of the engine below the heating element, which is why both cylinder block and oil pan heaters are necessary for a properly winterized vehicle that will have to operate at temperatures at which the engine oil may become too viscous for proper lubrication on start-up.

Lower radiator hose heaters usually take the form of a short tubular segment containing the heating element. This is inserted into the radiator hose with the removal of a short length of the original hose, as shown in Figure 7. They are usually equipped with a thermostat and are rated at about 400–600 W.

7. Design and location of a typical coolant immersion heater for installation in the lower radiator hose.



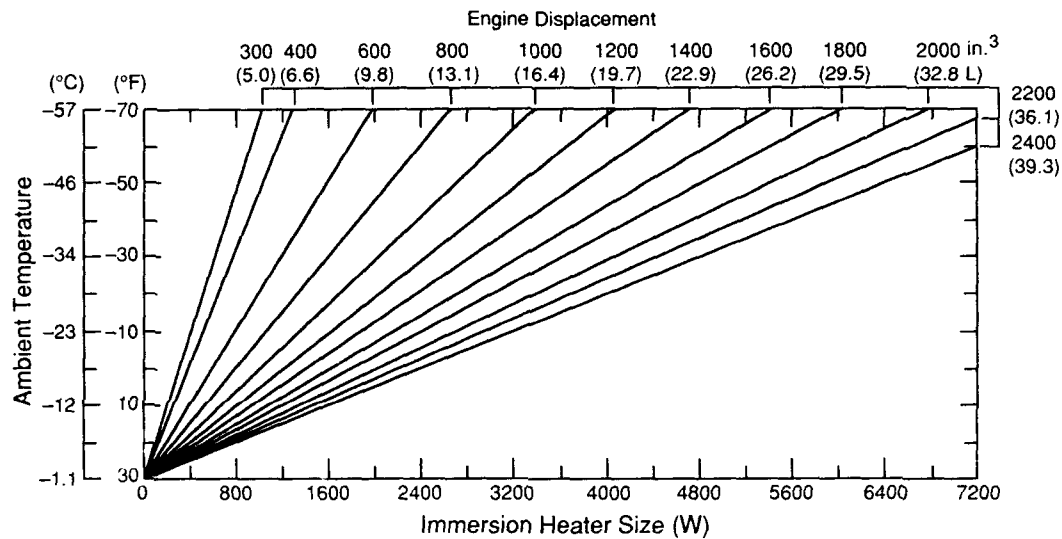


8. Heating curves for different sizes of coolant and oil pan immersion heaters tested in a cold-soaked, uninsulated engine. Note that the curves represent temperature rise rather than final temperature attained and that after about 5 hours the greatest temperature differential that can be maintained by the heater has been attained. These curves will differ for other engines, degrees of insulation and wind conditions, but the general shapes will be similar. (After Stupich 1987.)

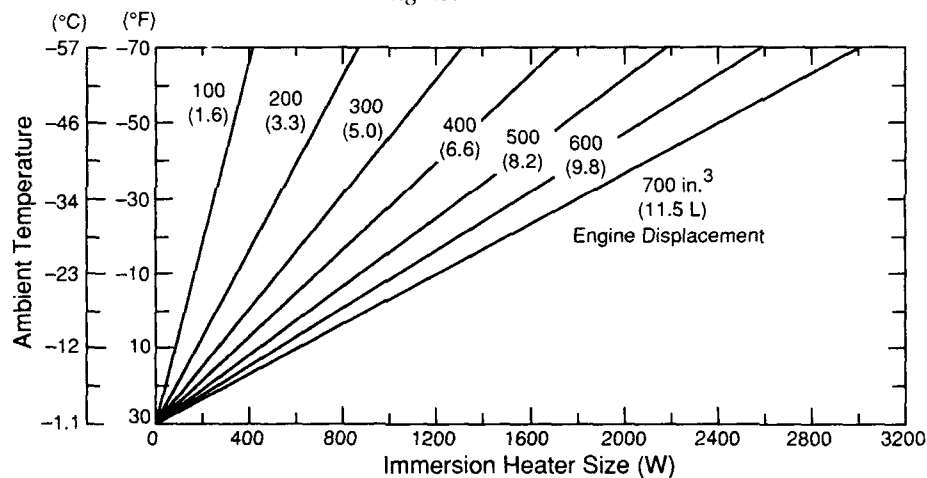
Freeze-plug heaters are available for virtually all automotive and construction equipment and must be used in the equipment for which they were designed. Depending on engine size, wattages range from as low as 400 W for automobile engines up to 2000 W for large industrial engines.

Detroit Diesel (1989) experimented with electric immersion heaters for both oil pan and coolant in an uninsulated 6V53 engine standby heating system. Heating curves for various sizes of heaters are shown in Figure 8. Detroit Diesel specified that a standby heating system should attain a final coolant temperature of 38°C and a final oil temperature of 16°C. By interpolating the data in Figure 8, it was determined that a 2.4-kW block heater and a 300-W oil pan heater were required to reach and maintain the target temperatures when the ambient temperature was -40°C.

Instead of installing the heater directly in the engine block, which can be difficult and may obstruct the flow of the coolant, the heater can be installed in one of the main coolant hoses. The coolant will circulate merely by natural convection. Since some of the heat will be lost to the engine compartment, more power will be required to



a. V-engines.

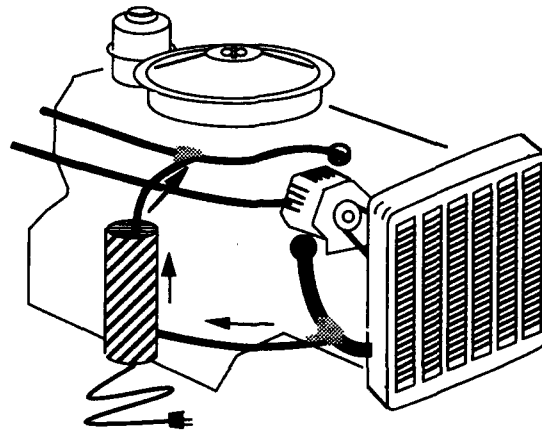


b. In-line engines.

9. Immersion heater wattage required to raise block coolant temperature to -1.1°C (30°F). (After Detroit Diesel 1989.)

reach the target coolant temperature; however, a beneficial effect is that other parts of the engine will be heated to some extent.

Figure 9 shows immersion heater wattages required to bring engines of various sizes up to -1.1°C (30°F) from the indicated initial temperatures. The curves are based on a 12-hour heating time with 80% of the temperature rise occurring in the first 5 hours. These curves do not take into account the effect of either wind or insulation, but they may be used as a general guideline for heating requirements. In general, these are stand-by heaters whose function is to maintain the engine in a startable state and would not normally



10. Configuration of a tank-type coolant heating system. The inlet taps into a low point in the cooling system, the heater is located near the bottom of the engine, and the outlet taps into a high point in the system.

be used alone to preheat a cold-soaked engine. Thus, the 12-hour heating levels may be taken to represent the temperature level at which the engine will remain when the heaters are activated when the engine shuts down.

Tank-type heaters are mounted in the engine compartment and are plumbed into the coolant system with hoses as shown in Figure 10. The Y connectors used to connect the heater to the existing coolant hoses should be made of metal, rather than plastic as commonly supplied, to avoid breakage. Since the fluid usually circulates through convection, the inlet hose is connected to the lowest possible location in the cooling system, such as the lower radiator hose or the radiator or block drain; the outlet hose is tapped into the water manifold or cylinder head. For proper operation the heater should be mounted low in the engine compartment. Some heaters are designed for vertical installation and some for horizontal; deviation from the design orientation will impair the flow, reducing the amount of heat distributed to the block and overheating the tank. Improper installation may irreparably damage the heater.

Heaters of this type have the highest power rating of the electric engine heaters discussed so far, ranging from about 500 to 4000 W. Their physical dimensions are also greater than those of other types, which may pose installation problems for some equipment. Thermostatic controls, pumps and ball check valves at the inlet are available on many models, either integral to the unit or as optional add-ons. Since the tank itself as well as the connecting hoses are exposed, some heat loss is inevitable, and a unit should have 50% greater wattage than would be required for an immersion heater (Fig. 9). A heater of this type should not be used at all in an uninsulated engine compartment.

Tank-type coolant heaters

Table 1. Recommended immersion and tank-type heater wattages for engines of different sizes. The maximum temperature rise in the engine will be achieved in 5 hours of heater operation; approximately 90% of this rise will take place after 2 hours, and 75% after 1 hour. The data were obtained from Phillips Temro, Inc.

Engine block displacement (in. ³)	Recommended power densities for heaters to be used at given temperatures				
	1 W/in. ³ at -18°C (0°F)	1.5 W/in. ³ at -23°C (-10°F)	2 W/in. ³ at -29°C (-20°F)	2.5 W/in. ³ at -34°C (-30°F)	3 W/in. ³ at -40°C (-40°F)
Immersion heaters					
100	100	150	200	250	300
200	200	300	400	500	600
300	300	450	600	750	900
400	400	600	800	1000	1200
500	500	750	1000	1250	1500
600	600	900	1200	1500	1800
700	700	1050	1400	1700	2100
800	800	1200	1600	2000	2400
900	900	1350	1800	2250	2700
1000	1000	1500	2000	2500	3000
Tank-type heaters					
100	150	225	300	375	450
200	300	450	600	750	900
300	450	675	900	1125	1350
400	600	900	1200	1500	1800
500	750	1125	1500	1875	2250
600	900	1350	1800	2250	2700
700	1050	1575	2100	2550	3150
800	1200	1800	2400	3000	3600
900	1350	2025	2700	3375	4050
1000	1500	2250	3000	3750	4500

Table 1 gives recommended heater sizes for engines ranging in size from 100 to 1000 in.³ at temperatures ranging from -18 to -40°C. Table 2 shows suggested heater types and sizes for expected ambient temperatures from -35 to -50°C. These recommendations are those of a major supplier of automotive heaters.

Fuel-fired heaters

These heaters are more suitable for use where electric power is limited or unavailable. Heat is produced by combustion of hydrocarbon fuels, and while some require electricity for pumps or blowers, in general this demand is small enough that it can be drawn from the vehicle's battery. Others require no electrical input at all, but these are not usually as versatile since the heat cannot be widely distributed through the engine and other components.

Table 2. Recommended heaters for diesel engines at temperatures ranging from -35° to -50°C . In addition, a battery warmer in an insulated battery box is recommended for all cases. A measured-shot ether kit may be used if necessary in accordance with the engine manufacturer's guidelines. The recommendations are from Phillips Temro, Inc.

<i>Starting aids</i>	<i>Small diesels (150–350 in.³; 2.4–5.7 L)</i>	<i>Medium-duty diesels (to approx. 550 in.³; 9.0 L)</i>	<i>Heavy-duty diesels (to approx. 1150 in.³; 18.8 L)</i>	<i>Large diesels (industrial and off highway)</i>
Coolant heaters	750-W immersion or 1500-W tank or 5000-Btu propane	1500-W immersion or 2000-W tank or 10,000-Btu propane	2000-W immersion or 2500-W tank or 30,000-Btu propane	2 × 2500-W tank or 30,000-Btu propane
Oil pan heaters	150-W immersion	300-W immersion or 500-W clamp-on	450-W immersion	450-W immersion

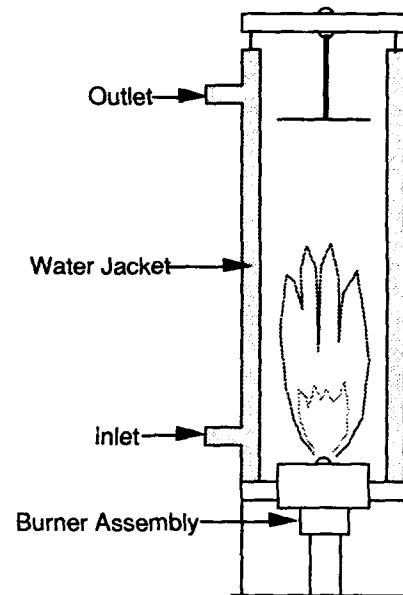
Most of these heaters are quite small and are mounted inside the engine compartment, where they are plumbed into the cooling system at the same locations as the tank-type heaters. The coolant is frequently circulated through convection alone, although some units include a small pump that draws its power from the battery. The larger types are mounted outside the engine compartment behind the cab or at some other convenient location and can pump heated coolant to various components, including the engine, battery, cab or anywhere else a heat exchanger has been installed.

Propane heaters are available for a number of applications and are useful when electrical power is limited. Their major drawback is that at temperatures below about -34°C (-30°F) the gas pressure is insufficient for proper functioning. If this type of system is to be used, either the propane tank must be kept above -34°C or a lighter gas must be used. Propane heaters are also subject to damage in high-vibration environments.

Tank-type propane heaters are similar to the electric-powered ones. The combustion chamber is surrounded by a water jacket through which the coolant flows, again by convection, as shown in Figure 11. The unit must be mounted vertically since the exhaust gases are vented through the top. They are rated from about 5,000 to 30,000 Btu (equivalent to about 1,500 to 9,000 W). A considerable amount of heat is lost in the exhaust gases. A beneficial effect of this in a well-insulated engine compartment is that components

Heaters mounted on
the equipment

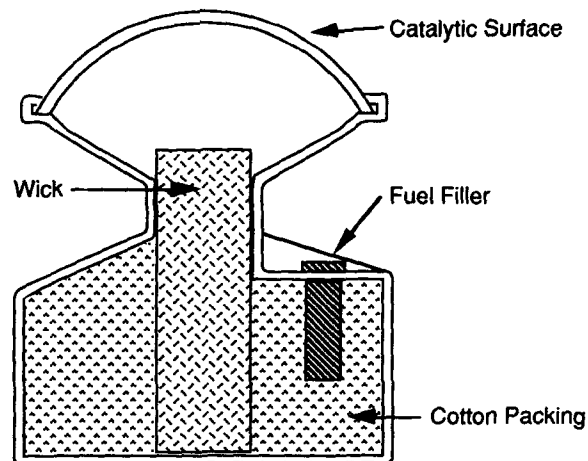
11. Typical
propane-fired
engine heater.



not normally heated, such as the starting motor, will be warmed by this waste heat. On the other hand, the water formed during combustion will almost certainly cause a certain amount of frost buildup, which may harm some engine parts.

Other types of propane heaters are used for space heating (e.g. equipment cabs and cargo and passenger compartments) and for quick-start applications. For example, a weed burner or blowtorch can be used in conjunction with a stovepipe to warm the oil pan, although this or any other method involving open flames is not recommended.

There are a number of very powerful and versatile gasoline and diesel-fired heaters commercially available for industrial applications. One type, similar to propane heaters, heats coolant in a water jacket surrounding the combustion chamber. This is then pumped through the engine and through heat exchangers in other parts of the equipment, such as the cab, the oil sump, the battery box and the fuel tank. The heater is externally mounted so that exhaust problems are not an issue. Such sophisticated systems usually include a control panel inside the cab that is used to direct the heated coolant to the desired areas. Many of these are programmable so that it is possible, say, to set the heater to start up at 3:00 a.m., heat the engine to a predetermined level and then divert some heat to the battery and cab. With heating capacities between 20,000 and 40,000 Btu (about 6–12 kW), these units can be used either for standby or quick-start heating, although the latter might take several hours.



12. Catalytic combustion heater.

Catalytic combustion heaters similar to that shown in Figure 12 produce flameless heat using gasoline, benzene or a similar fuel and have reportedly been used with success at temperatures of -50°C and below. The gasoline reacts with atmospheric oxygen on the surface of an inert layer such as asbestos or a ceramic material impregnated with platinum salts, which catalyze the reaction. The reaction takes place at about $200\text{--}370^{\circ}\text{C}$ and is initiated by heating the reaction surface by igniting a small amount of alcohol on it or by using a blowtorch. It is extinguished by covering the reaction surface. The intensity of the reaction depends on the concentration of the platinum salts. For safety reasons the fuel tank of these units is usually packed with cotton. Heaters of this type have reportedly been used to heat engine compartments and cabs.

Thermoelectric generators are reportedly very reliable, if costly, devices that convert heat directly to d.c. electricity through a solid-state energy converter. Large stationary models, often used in remote data-gathering installations, normally use gaseous fuels. They produce electrical power at about 7–9% efficiency and produce a large amount of waste heat. However, a small unit has been designed for use on automotive equipment and uses diesel fuel, kerosene or gasoline. Heat from combustion of the fuel is applied to one side of the energy converter. The other side is cooled by circulating engine coolant. The resulting temperature differential causes d.c. power to be produced. The electricity produced runs the pump, and any excess power can be used to charge the battery, if desired. The net power output is about 60 W at 24 V. The waste heat directed through the coolant to the engine and other components amounts to about 20,000 Btu (about 6 kW). The maximum power required for start-up is about 420 W (15 amps at 28 V), but the unit

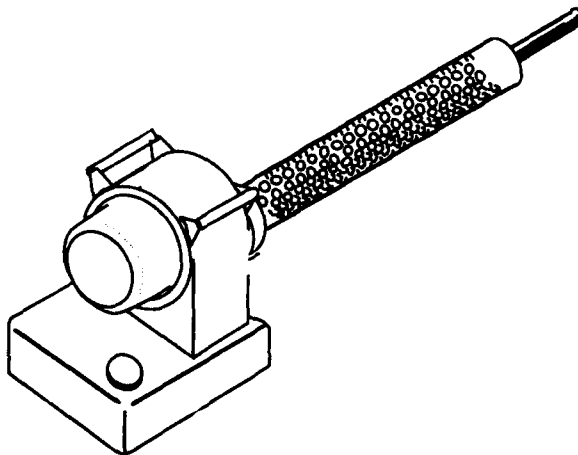
is self-sustaining during normal operation. Units with a greater power output are under development. These heaters, in spite of their high cost, appear to have great potential value in cold regions where electric power is limited.

Heaters external to
the equipment

One of the principal virtues of heaters that can be decoupled from the equipment is that there is really no limit to their physical size or power output. In addition, one heating unit can be used to heat a number of vehicles, and if the unit is kept in a warm area, there should be no problem starting it up when it is required. On the other hand, it takes time to heat a piece of equipment sufficiently to start, and this time cannot be reduced by increasing the rate of heat delivery without risking damage from excessive temperature rise. About 15–20 minutes seems to be the practical lower limit for preheating time at very low temperatures in a vehicle with a good coolant distribution system. Thus, preheating ten vehicles in this way may take five hours or more.

The Espar Swingfire heater, widely used by the U.S. military and NATO in their northern operations, is a gasoline-fired pulse-jet engine that requires only 15 W of battery power for start-up and no electric power during normal operation. The combustion products are under pressure and are exhausted from the heater with considerable velocity, which enables the heat exchangers that are used with these heaters to use exhaust-driven turbines. Figure 13 shows the basic unit, which is used in conjunction with a variety of heat exchangers so that the same heater can be used as coolant heater, space heater, forced-hot-air heater, tank heater (such as fuel tanks), etc. For use as an engine coolant heater, a water-jacket heat exchanger is permanently installed on the equipment, and the heater is moved from one machine to the next. Thus, several pieces of

13. Swingfire pulse-jet gasoline-fired heater. This versatile heater can be used with numerous different types of heat exchangers for engine and space heating.



equipment can be preheated with one heating unit. The heating capacity is about 40,000 Btu/hr (about 12 kW) and can bring a properly winterized vehicle up to starting temperature in as little as 20–30 minutes, depending on the engine size and the ambient temperature. The coolant should be circulated during this process. Engines at -40°C have been started within an hour using this heater, and standby heating is also possible. The reliability and ease of maintenance has had mixed reviews. A drawback to their use is their reported tendency to shoot flames out the end of the combustion chamber at very low temperatures.

Hot coolant transfusion systems, another external form of heater, require inlet and outlet hoses patched into the vehicle's cooling system with quick-disconnect fittings so that heated coolant from a source outside the vehicle's engine can be pumped through the cold engine, reaching all heat exchangers in the engine including, where present, those in the battery box, the oil pan and the fuel line. In some cases the coolant from a warm pick-up truck can be pumped through a larger machine using quick-disconnect connectors. If this is done, it is important to disconnect the pick-up truck before starting the larger equipment, or the larger engine will tend to suck the coolant out of the smaller, with unhappy results. Large diesel equipment with gasoline starting motors usually have a shared cooling system. In this case the gasoline engine can be run until the diesel engine is sufficiently warm to start.

Systems are available that were designed specifically for hot-coolant transfusion and basically consist of a boiler and a circulating pump. If a system of this type is to be used, it makes sense to heat as many necessary components as possible, such as those mentioned above. This involves a certain amount of modification of the engine to accommodate the required heat exchangers. If a fuel heater is to be installed, it should be located before the primary fuel filter and be equipped with a thermostatic cut-off to avoid overheating the fuel.

Canadian investigators have tested hot-coolant transfusion systems that use an Espar D24W (24-kW output) heater (similar to the Swingfire heater), a pump and a coolant reservoir tank (Shankhla et al. 1987b,c). Electric power consumption is high but only for a short time. Electricity is needed to start the heater and power the pump and can be obtained from the vehicle being heated or preferably from the vehicle used to transport the heater. Valves were installed in the main coolant circuit and in the oil pan coil circuit to permit the flow to these elements to be adjusted. The vehicles used in this study had 300-in.³ (5.2-L) engines with a coolant capacity of 36 quarts (34 L) and an engine oil capacity of 18 quarts (17 L).

During this 21-day study the control vehicle would rarely start when cold-soaked to -10°C , while similarly cold-soaked vehicles, preheated using the hot-coolant transfusion system started easily down to -40°C . At this temperature about 30 minutes of preheating were required; at -20°C , 10 minutes were required.

In similar tests of the D24W on engines with coolant-heated engine blocks, oil pans, batteries and fuel, the heater raised the engine temperature by 80°C , the oil temperature by 40°C , and the fuel temperature by 45°C within a 15-minute period. It seems clear that this heating system is capable of bringing a cold-soaked vehicle up to starting temperature in 20–30 minutes even at temperatures down to -40°C . Further, by using quick disconnects, it can be used to preheat a number of vehicles sequentially.

Hot air can also be used to heat air-cooled engines. The combustion products from a heater can be used either directly or diluted with fresh air. Batteries may be enclosed in an insulated box through which the contaminated air circulates, but the system must be equipped with thermostatic valves to cut off the heat supply before the battery is damaged. Heaters of this type are built with burners that have high excess air (low CO_2) to produce a large volume of comparatively low-temperature exhaust gases. Finned battery terminal connectors that enhance the ability of terminals to extract heat from a passing stream of hot air have been developed. Exhaust gases have also been used for this purpose. To prevent damage to the battery from the very high temperatures and corrosive nature of exhaust gases, double-walled battery compartments have been used to protect the battery from direct contact with these gases.

Water-cooled engines can be heated by hot air on the outer surface, but time is required for the heat to be conducted into the heart of the engine. Hot air could instead be blown into the air intake, thereby heating the combustion air as well as a portion of the engine. When hot air is used to heat a water-cooled engine, a high proportion of the air within the engine compartment will be warmed. Warm air throughout the engine compartment would heat many parts and subsequently reduce the frequency of component failures related to cold embrittlement and differential thermal expansion of materials. A fully enclosed engine compartment would certainly amplify the benefits of heating with hot air. Heat retention brought about through the use of grille shutters or covers, or vehicle insulation, would provide further enhancements. An additional feature is that the starter and other components that frequently freeze could easily be thawed by having some of the hot air directed at them. A frozen starter would present more of a problem if the vehicle's winterization kit used only a coolant circulating heater.

Air-cooled engines can also be heated with fresh hot air blown to the important points. This system uses a heater with a large heat-exchange surface and a powerful blower to propel fresh air over the surface, then through ducts to the point of application. Herman Nelson heaters are commonly used in conjunction with the elephant's trunk conduits shown in Figure 2.

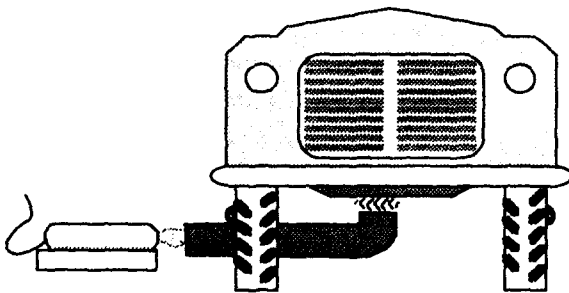
Figure 14 shows a crane with an enclosure housing the engine and winch mechanism. The cab communicates with the engine enclosure through a door. When necessary, this machine is effectively warmed using a kerosene space heater placed in the rear of the engine compartment. The doors and vents are covered, and the machine may be sufficiently warm to operate in an hour or two, depending on weather conditions.

A common practice is to place a chimney pipe under the vehicle to be heated with an elbow directed upward toward the underside of the engine. Intense heat can then be directed into the pipe from the

Expedient methods



14. Enclosed engine and winch mechanism of a crane, which can be heated using a kerosene space heater located on the catwalk within the engine compartment. This is a simple and effective technique on equipment with this sort of enclosed design.



15. Stovepipe used in conjunction with an external heat source to warm the underside of an engine.

front or side of the vehicle, as shown in Figure 15 using a master heater, weed-burner or similar device. A master heater burns liquid fuel and contains an electric fan to blow the heated air out of one end of the tubular combustion chamber. A weed-burner does not contain a fan and is therefore not able to heat objects at any distance from the flame. It is never a good idea to use intense heat directly on metal parts as this is likely to char lubricants, damage seals, and even melt aluminum parts.

A bed of hot coals or a pan of burning oil has been used for engine preheating. This or any other method involving open flames is not recommended due to the likelihood of incinerating the vehicle.

A common practice in former times was to drain the warm oil or coolant or both on shut-down and store it in a warm place overnight. The fluids were then replaced when the engine was to be restarted in the morning. This is effective but exceptionally inconvenient in most cases.

The Soviets have used infrared radiation generated by a gas burner for heating automotive equipment. Their unit appears to be compact and lightweight, consisting of a gas jet and a combustion chamber with a reflector behind it. The gas burns on the surface of the combustion chamber, generating temperatures of 800–900°C. The reflector directs this heat on the area to be warmed. It is said to generate between 2200 and 5800 kilocalories/hour of heat (equivalent to about 2500–6500 W), depending on the size of the unit. Infrared heaters of this type are commonly used in North America for heating factories, warehouses and the like, their principal virtue being that they heat objects rather than the air, making exfiltration of heated air less important; however, they have not been widely used for vehicle preheating. Banks of heat lamps have also been used.

Continuous idling

A frequently used method of standby heating involves continuous idling of the engine throughout the period of cold regions operation. In general, this is not a good idea since a wide variety of vehicle problems result because idling doesn't allow the engine to attain normal operating temperatures at low air temperatures. Many vehicle components remain cold throughout extended periods of operation, which results in increased failures. Some engines are designed to perform best under full load, which has been cited as a reason for their failure under conditions of prolonged idling. Prolonged idling has been held responsible for causing low airbox pressures, poor injector performance, excessive vibration and torsional loads, electrical system failures and many other problems. The loss of airbox pressure allows oil to leak into the airbox, where

it can mix with carbon ash fragments and form a sludge that adheres to the rings and valves and plugs liner ports. Since injectors are designed for optimum performance at high rates of fuel consumption and experience difficulties at low engine speeds, long periods of engine idling reduce injector performance and lead to injector jamming. Excessive vibration and torsional loads result from one or more cylinders not firing or firing only intermittently. Electrical system problems ranging from alternator breakdowns to voltage regulator, generator pulley and generator field switch failures have also been attributed to continuous idling. Sludge buildup is greatly increased during idling, and of course, fuel and oil consumption are needlessly high.

An early indicator of excessive idling and low engine operating temperature is a black, oily "slobber" coming from the exhaust pipe or stack. As soon as this slobber is noticed, proper operating procedures should be implemented. In general, this involves increasing the idling speed to about double the normal idling speed in order to increase engine temperatures. Usually the slobber will immediately clear up. If it is allowed to persist, an engine failure is imminent. Whenever an engine is idled for more than a few minutes, the idling speed should be increased.

Once the engine has been started and is operating normally, any excess heat that it produces can be diverted through the cooling system or air ducts to heat exchangers in other parts of the vehicle, such as the cab, cargo compartment or hydraulic reservoir. The greater the degree of winterization of the engine, the more heat will be available for these purposes. Ideally heat retention devices should enable the engine to reach the desired temperature range of 85–93°C under extremely cold conditions.

Arctic and Antarctic operators of heavy equipment frequently locate the air intake inside the engine compartment, both to prevent snow from obstructing the air supply and to provide heated air for combustion. On some machinery the engine compartment can be completely enclosed. With the fan mounted backwards so that it draws air through the radiator and into the engine compartment, the latter is slightly pressurized and a considerable amount of heat is supplied to components not normally warmed, such as the transmission and hydraulic pumps.

The use of circulated coolant offers the most efficient means of distributing excess engine heat to other parts of the equipment through strategic placement of heat exchangers. Coolant is moved through pipes and hoses much smaller than the bulky ducting

Using excess engine heat

Coolant heaters

required by hot air systems, and the heat can be easily and effectively delivered to small areas and specific components, such as batteries, air intakes and fuel lines. Circulated coolant is commonly used for defrosting windshields and heating the personnel compartment and sometimes the cargo compartment as well.

Exhaust gases

Exhaust gases are also a potential source of heat for various components. Systems for heating batteries, intake air, oil pans in unenclosed engine compartments and other components have been used successfully. The beds of dump trucks are commonly warmed by running engine exhaust through a double bottom. This prevents material from freezing to the bed. There are problems with using exhaust gas, though, because the fumes are poisonous and corrosive, requiring that special precautions be taken and only certain materials, which are usually expensive, be used. Moreover, there is a limit to the amount of heat that can be extracted from the exhaust before serious problems with wet stacking and slobber develop.

A modification of the contaminated-air system carries the products of combustion through ducts and heat radiators adjacent to the points to be heated so that engine parts are protected from contact with the combustion products. A combination of radiators and direct heating using exhaust gases can be designed to obtain fairly high heating efficiency with protection for personnel and all delicate parts of the equipment.

Cold starting

Cold starting of internal combustion engines of all types is a major problem. Difficulty in successful cold starting begins at about -1°C and becomes worse as the temperatures decrease. Even the use of winterization kits may not ensure quick and reliable starting at temperatures of -40°C and below. Although many factors are involved, the most critical problems are the reduction of battery power available for cranking and the increased viscosity of the engine oil. Both of these problems have been discussed elsewhere and will not be considered here (Diemand 1991a,b).

Starting a diesel engine is far more difficult than starting a gasoline engine because of the nature of the fuels and the combustion process. The power required for starting may be as much as five times greater for diesel engines than for equivalent gasoline engines. This section, therefore, deals primarily with methods to improve cold starting performance of diesel engines.

Some simple techniques have been developed by operators with long experience in extremely cold environments. On large equipment with a gasoline starting motor, provision can be made to prevent compression buildup in the cylinders. With the exhaust

plugged, the fuel supply turned off and the compression off, the engine is turned over slowly with the starting motor. Since cold air is not being drawn through the engine, it will warm slightly due to friction and will turn over more easily after a time. When it is turning over relatively easily, the exhaust is uncovered and the fuel and compression returned to normal settings, and the engine can be started.

The cold-starting capabilities of vehicles can be improved in a variety of ways. Special preparations for cold regions operations can be made either to increase the attainable engine cranking speeds or to improve the characteristics of the fuel-air mixture reaching the combustion chamber. The chances of successful starting can be increased by using one or more of many heating systems to elevate vehicle temperatures, or the probability of ignition in an unheated engine can be increased by using starting aids such as glow plugs and ether injection.

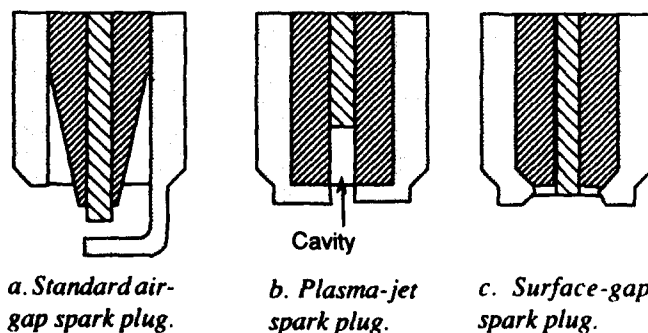
Cold-engine starting aids include factory built-in or permanently installed devices or accessories that enable internal combustion engines to start at temperatures down to -30°C . The aids are used in conjunction with winterized engine adjustments and modifications and prescribed low-temperature fuel and lubricants. Because the aids are permanent parts of the engine, they ordinarily do not interfere with normal equipment operation.

A glow plug consists of an electrical resistive element that projects into the combustion chamber of a diesel engine. Generally, when a glow plug is energized, it heats up to about 900°C and thereby aids ignition by warming the combustion chamber and the air-fuel mixture. Glow plugs have become more common in recent years as diesel engines have become increasingly popular for passenger cars.

Glow plugs

There are three types of spark plugs used occasionally to assist in starting diesel engines (Fig. 16). Plasma plugs are similar to

Spark plugs



16. Cross sections of spark plug types. (After Dale et al. 1985.)

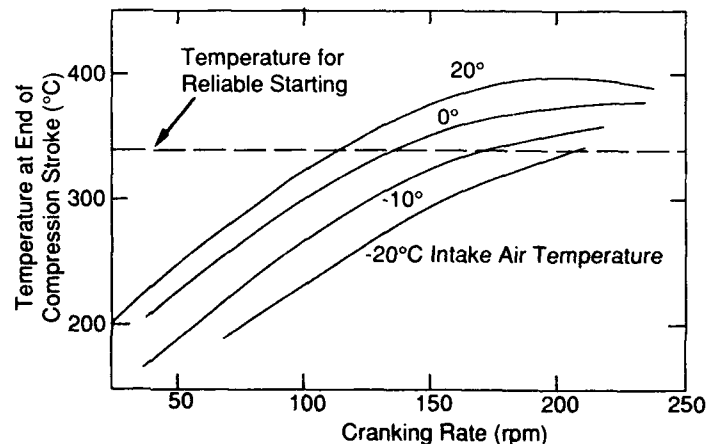
surface-gap plugs in that the spark travels along the ceramic surface rather than through air, as in the familiar air-gap type. The appeal of the surface-gap types appears to lie in their smaller power requirement to produce a spark.

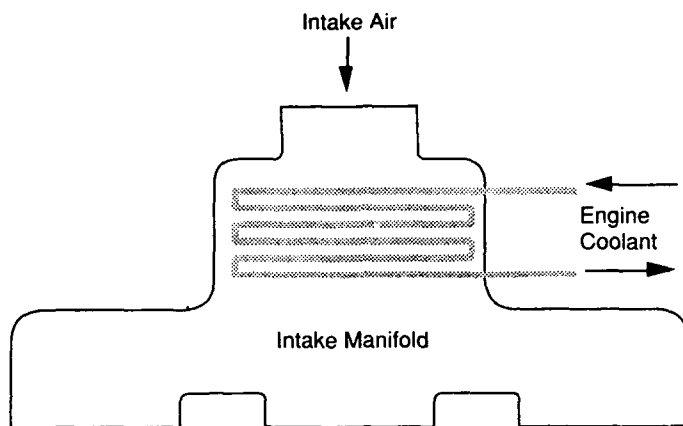
The plasma plug uses a spark generated by a high-voltage capacitor to increase the probability of fuel ignition. The voltage required to generate the spark is much less than for an air-gap plug. Tests indicate that a timed spark discharge system similar to that used in gasoline engines greatly increases the low-temperature starting capability of a diesel engine. After starting, the system is turned off. Tests with a particular engine showed it would start down to the cloud point of the fuel (-50°C) using the plasma plug ignition system (Dale and Santiago 1984, Dale et al. 1985). The effectiveness of the system compared to glow plugs varied somewhat with the engine being tested, but it was more effective in all cases. In some cases, glow plugs enabled starting after a shorter duration of cranking than was possible with the plasma plugs. Although the plasma plugs themselves draw less power than the glow plugs, the increase in battery power draw associated with the increase in cranking time makes up for the difference in overall power consumption.

Heaters for the intake air

The importance of heating the intake air is demonstrated by Figure 17, which shows that for a given decrease in air temperature, twice that drop is experienced by the combustion chamber. For example, inlet air at 20°C will result in a 340°C combustion chamber temperature at a modest cranking rate, while -20°C inlet air temperature will yield only 250°C at the same cranking rate. Similarly, while the engine will start with a cranking speed of 120 rpm at 20°C , more than 200 rpm is needed at -20°C and below.

17. Effect of intake air temperature and cranking rate on the temperature at the end of the compression stroke of a diesel engine. This clearly demonstrates the value of increasing the intake air temperature. (After Smolin 1968.)





18. Schematic drawing of an engine coolant heat exchanger used to preheat combustion air. (After Stupich 1987.)

Diesel fuel ignites at 270–336°C. Reliable starting should be assured if the cylinder temperature at the end of the compression stroke reaches 340–345°C. This temperature is strongly influenced by both the air temperature and the cranking speed. Normal diesel starter cranking rates are about 100–200 rpm. The data given in Figure 17 for intake air temperatures from 20° to –20°C suggest that starting will be difficult or impossible at intake air temperatures much below –20°C. However, installing a heater in the air intake path, such as in the intake manifold, will result in a temperature rise in the cylinder more than twice that in the intake air flow.

In a test program on some commercial diesel vehicles over several winters, a small coolant heater similar to that shown in Figure 18 was installed in the intake air stream. It proved very reliable and eliminated all cold-weather combustion problems in these vehicles at very low temperatures. With a coolant temperature of 60°C the temperature of the intake air could be increased from –32 to +27°C. Electric air intake heaters are also available and usually take the form of a heated screen. If these are used, ether injection should be avoided because of the danger of explosion in the intake manifold.

Some airbox heaters burn fuel to warm the intake air before it is drawn into the combustion chamber. Fuel is drawn from the fuel tank, and an electrical spark is used to ignite it inside the airbox. Low-temperature starting tests revealed that operation of the airbox heater was tricky; if operated for an insufficient period it did little to aid starting, and if used for too long it consumed too much of the oxygen in the intake air, starving the cylinders and preventing the engine from starting. If spark plugs are used as a component in an air intake heating system, the use of an ether starting fuel should be avoided, as it can ignite in the airbox or manifold, with consequent damage or injury.

Other cold starting aids

Fuel is sometimes introduced into the cylinder or intake manifold during the intake process so that the fuel will have longer to evaporate. Another technique is to limit the exhaust valve opening during cranking, which causes some of the compressed mixture in the cylinder to heat the incoming intake gas and thus raises the compression pressure and temperature.

Engine cycling

Idling problems can be decreased by reducing the amount of time an engine is idled. An engine can be started and stopped at intervals to ensure that it always remains warm enough to start. This can be done either manually or by using an automatic engine cycling device that monitors and reacts to engine temperature. Such devices are commercially available.

Canadian investigators studied engine startability at temperatures ranging from about -10° to -20°C using four machines equipped with an automatic engine cycling system, one cold-soaked control vehicle and one left continuously idling (Shankhla et al. 1987a). Their findings were that vehicles controlled by automatic engine cycling systems started immediately and reliably at all temperatures, while the cold-soaked machine would not start reliably below -1°C and would seldom start at all below -12°C . Fuel consumption of the continuously idled vehicle was about 250 gallons for the duration of the 20-day test, while the cycled vehicles each consumed about 40 gallons. Engine oil consumption was similarly reduced. While the proportion of the time the engine is on will increase at temperatures below those of this study, the savings in a properly insulated engine would still be considerable. In addition to the reduced operating costs due to lower oil and fuel requirements, maintenance costs would probably also drop.

Conclusion

The primary goal in heating equipment at very low temperatures is to warm the engine sufficiently to achieve a successful start. Once the engine is running, it should produce enough heat to warm other components such as the battery, cab and so forth. The importance of a properly winterized engine compartment lies first in reducing the amount of heat required to warm the engine sufficiently to start and second in retaining heat generated during operation so that enough is available for secondary applications. If additional heat is required, numerous auxiliary units are available and can be installed in the cargo compartment or other areas to be heated.

There are no ironclad rules governing the choice of heaters since each piece of equipment will have slightly different requirements depending on its engine size, configuration, condition, lubricants, environment, degree of insulation and so forth. This report de-

scribes heaters of various types in common use in the cold regions of the United States as well as some unconventional methods and systems used elsewhere. It is up to the operators, however, to decide which of these is best for their equipment.

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